Semi-Annual Progress Report

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Ocean Productivity

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Period Covered - July 1992 through January, 1993.

Ocean Primary Productivity and Group Coordination

The objectives of my work continue to fall into two tasks:

Development of a Global Primary Productivity Algorithm for MODIS.

Coordination of the MODIS Ocean Group and interface with the SeaWiFS Project.

In many instances these tasks overlap considerably. I will update the task objectives for each, and discuss work accomplished singly and then jointly.

The objective of the Global Primary Productivity Algorithm is a major undertaking of the MODIS Mission for Oceans, and indeed is a primary objective of the NASA Ocean Color Program. The goal is to have at launch a credable algorithm to determine oceanic primary production using primarily MODIS data.

Work in using remotely sensed observations of ocean color is proceeding along two very different approaches. One is concerned with our ability to quantify global annual production, the other is oriented toward estimating daily net primary production on the pixel level. My personal research efforts are directly concerned with the former, but I am spending a significant amount of time and effort to assure that the latter approach progresses as well. For example, it is necessary to have good estimates of daily integrated photosynthetically active radiation for the daily approach, and therefore I have agreed to provide the algorithm for this standard product.

The global approach is based empirically upon the relationship between in-situ measurements of annual primary production for different oceanic ecosystems or regimes. This is an extension of the work begun by Eppley et. al., and is being conducted in a collaborative fashion with Dr. Richard Iverson of Florida State University. Dr. Iverson has spent three summers at GSFC as part of

the Goddard visiting faculty fellowship program, and plans to complete a fourth this summer.

My initial results in developing this approach utilized Eppley's relationship which was based on a plot of averaged daily production values and Csat, the surrogate for a satellite-derived chlorophyll pigment concentration which can be calculated from in-situ data. This relationship is a power function. I used this relationship, and later a modification of it developed by Iverson and me, to estimate global annual production from CZCS observations. These estimates used monthly averaged satellite data, and I attempted to account for the severe undersampling by CZCS by forming zonal means. The net result was that we were able to arrive at meaningful estimates which fit within the framework of other global syntheses. Figs 1, 2, Table 1). However, upon further analysis, we determined that the approach gave highly questionable results for given regions and for particular time periods.

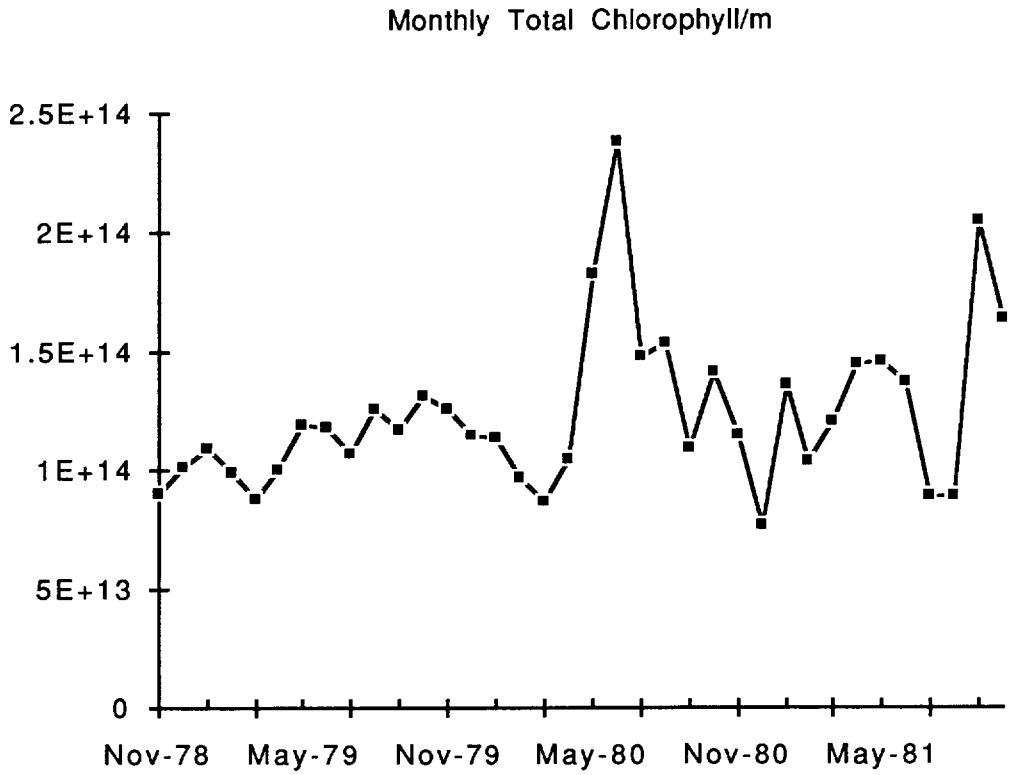

Figure 1. Time series of global mean pigment concentration from CZCS. The large deviations are due to severe undersampling of the southern ocean.

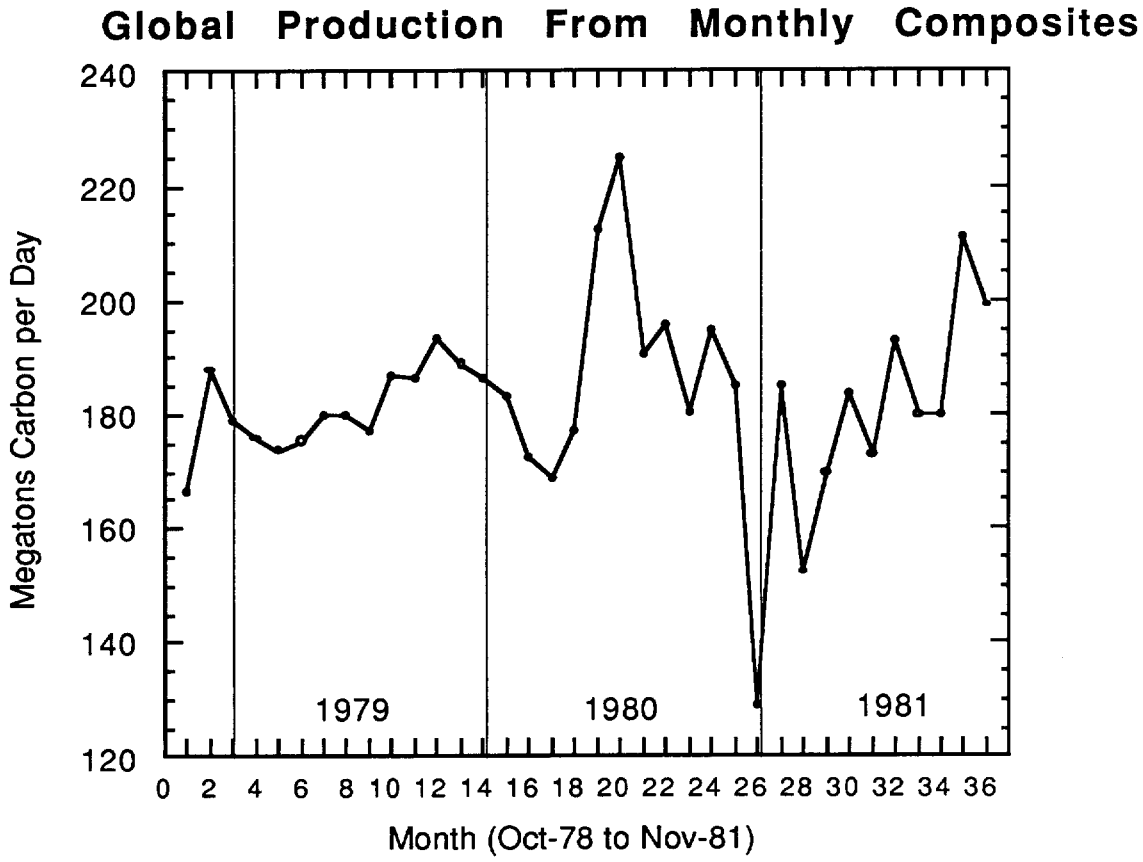

Figure 2. Global Primary Productivity time series derived from application of annual relationships to monthly mean pigment observations from CZCS. The average annual number derived from such a relationships differs significantly from the average annual productivity calculated from a global annual average due to undersampling.

Table 1. Average Pigment Global Concentration from CZCS Zonal Analysis for three 12 month periods

Global CZCS Pigment Concentration

Month	Average Chl (mgChl/m^-3)	Month	Average Chl (mgChl/m^-3)	Month	Average Chl (mgChl/m^-3)	
Nov-78	0.3508	Nov-79	0.4579	Nov-80	0.4289	
Dec-78	0.4774	Dec-79	0.3636	Dec-80	0.3333	
Jan-79	0.4526	Jan-80	0.4741	Jan-81	0.4723	
Feb-79	0.3425	Feb-80	0.2640	Feb-81	0.4271	
Mar-79	0.3038	Mar-80	0.2473	Mar-81	0.4732	
Apr-79	0.3959	Apr-80	0.4470	Apr-81	0.6153	
May-79	0.6095	May-80	0.7714	May-81	0.7643	
Jun-79	0.6013	Jun-80	1.1320	Jun-81	0.5887	
Jul-79	0.5304	Jul-80	0.7541	Jul-81	0.2624	
Aug-79	0.5780	Aug-80	0.7032	Aug-81	0.2624	
Sep-79	0.5065	Sep-80	0.5764	Sep-81	0.8556	Grand
Oct-79	0.5608	Oct-80	0.6223	Oct-81	0.7063	Mean
Mean	**0.4758**		**0.5678**		**0.5158**	**0.5198**
Standard Deviation	0.1067		0.2501		0.1930	Standard Deviation **0.04612**
Coefficient of Variation	**22.42%**		**44.05%**		**37.41%**	Coeff. of Variance. **8.87%**

We have recently refined the approach, and have studied its limitations. We, like others before us, now understand that both extrapolation of empirical relationships within, as well as beyond, the time periods resolved in the data, is dangerous, and inappropriate. We have instead concentrated on increasing the breadth of the data by adding additional regions from which good estimates of annual primary production can be obtained. In order to increase the number of such time-series stations, it was necessary to develop a method which accounts for the changes in techniques for making in-situ measurements from standard to ultra-clean techniques. (Iverson). When these procedures are applied, there now exists a fairly robust, linear relationship between annual production and annual mean Csat for about 90% of the world's oceans

(Iverson and Esaias, in prep, fig 3). Furthermore, the relationship between annual mean Csat and annual new production for these areas is also linear and nearly as robust. The empirical relationship developed by analysis of in-situ data appears equally satisfactory when applied to satellite-derived values of pigment concentration.

The significance of these findings is as follows. The global composite image from CZCS, to the extent that its values represent a true annual average, provides a directly proportional image of both primary production and new production. The conclusion is on annual and large scales and for equilbrium systems, the great disparity between biomass and production does not exist.

We now feel confident in this approach, and are in the final stages of submitting this paper for publication. The next steps in the approach call for re-examination of the CZCS data set to determine whether it might be possible to address inter-annual variability for certain large regions. Clearly there is insufficient sampling frequency to form robust annual averages from the data for most regions. We will try to quantify errors in making such estimates from limited numbers of observations. Additionally, we will continue to identify more regions for which adequate in-situ data exist to form annual averages of primary and new production. We have identified problems at very high latitudes in that those data fall outside the tight relationships illustrated, due presumably to severe light limitation during a significant part of the year.

Dr. Iverson is a member of the SeaWiFS Science Team, and we will work closely on this problem in preparations to use SeaWiFS data in this research. At the same time, I will be able to provide definition of this algorithm for MODIS with preliminary parameters and regions of application.

A ramification of this research for in-situ validation studies is that field programs need to provide good annual productivity time series of ecologically distinct regions. This is in keeping with Dennis Clark's work, but would argue that participation on various survey cruises which are not revisted 6 or more times per year will not lead to data which can be included the analyses.

Daily Production Algorithms

The development of an algorithm for daily production is much more difficult, but nevertheless is the chosen approach for most of the SeaWiFS science team members who address productivity. The importance of the approach is that daily production per unit area is absolutely essential for many process oriented investigations, particulary those concerned with daily to intra-annual variability The difficulties in this research stem from the facts that marine ecosystems are virtually never in equilibrium on a daily basis, and the values of several physiological parameters which must be assigned in algorithms developed between chlorophyll concentrations (or pigment concentrations) and photosynthesis and biomass changes, can vary widely and rapidly (certainly within a factor of 4 and perhaps more) due to nutrient stress, light history, trace material concentration, and the like, and very probably have important differences at the species level.

One is left with the need to arrive at a viable means of predicting these parameters on a daily basis, and to estimate the errors in these predictions. This approach requires the development of well posed coupled physical and biological models, ways of assessing the spatial and temporal variability of the important parameters, as well as the depth and species dependencies. There is great debate in the Biological Oceanographic community on whether an algorithm is possible, and if so, whose or what approach should be followed. Choices range from applying photosynthetic quantum models based on absorbance, to estimating various constants defined by different light and nutrient dependencies, and for various depth levels to integrated water column values.

The overall approach is very much undecided, and there is certainly no concensus of even what form of relationship to be used. In recognition of these factors, NASA wisely chose to make productivity the major thrust of the SeaWiFS Research Announcement, with my encouragement and support. A large portion of the team will investigate various approaches to the problem of estimating daily productivity. As leader of the SeaWiFS Science Team, I will make every attempt to ensure that MODIS needs are met through this approach. A Primary Productivity Group has been formed within the SeaWiFS Team. The chairman is Dr. Paul G. Falkowski of the Brookhaven National Laboratory, and tentative

membership is given in Table 2. The feeling of the entire SeaWiFS Science Team was that a preliminary standard daily production algorithm, which could gain the concensus of the group, may be available perhaps 2 years after SeaWiFS data begin flowing, ie. spring 1996. Estimates on what computer resourses, ancillary data, and non-MODIS data will be required for implementation vary considerably.

With respect for MODIS, the difficulty that this schedule presents is our inability to completely define computing requirements, but is partially relieved in that the daily productivity is a post-launch product.

TABLE 2. SeaWiFS Primary Productivity Working Group

SeaWiFS Science Team
Primary Productivity Working Group

Paul Falkowski, Chair
Mark Abbott
Kevin Arrigo
William Balch
Wayne Esaias
David Glover
Richard Iverson
Dale Kiefer
Rueben Lara-Lara
Marlon Lewis
Charles McClain
Greg Mitchell
Andre Morel
Frank Muller-Karger
Raymond Smith
John Walsh
Charles Yentsch
Jim Yoder

Coordination with the MODIS Ocean group and the SeaWiFS Science Team is a second primary function. This task has been addressed through joint meetings between SeaWiFS working groups and the MODIS Ocean Group. This arrangement has worked well to dispell the fair degree of discomfort expressed by SeaWiFS team members and better funded MODIS Ocean Group members. A great deal of time has been expended in making sure that the separate tasks performed by MODIS members for SeaWiFS is well justified and understood by our management at GSFC and HQ.

Both of these functions are aided considerably by the work of Lisa Rexrode of GSFC, and the Silicon Graphics workstation purchased under MODIS funding. The SGI is networked within the SeaWiFS computing environment, and maintenance costs are borne by me. I plan to expand the hard disk capability and other peripherals this year. This arrangement has enabled a much better computer environment for the MODIS work than would have been possible independently.

Future Actions

The MOCEAN Group will meet with the SeaWiFS Science Team executives in a joint session to discuss field validation efforts, at the upcoming Science Team meeting.

I am defining a series of joint SeaWiFS/EOS Color and MODIS level 3 data products which would be produced routinely. An issue is the responsible entity for producing such products, and budgets required.